EXPERIMENTS ON PLANAR PLASMA FLOW SWITCHES AT LOS ALAMOS.*

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We have performed a series of experiments on the Colt facility at Los Alamos to study the performance of plasma flow switches and to understand the important physics issues which affect that performance. These experiments were done in planar geometry on a small machine to allow for better diagnostic access and a higher repetition rate. The Colt facility is a capacitor bank which stores 300 kJ at maximum charge and produced a peak current of 1.1 MA in 2.0 microseconds for these experiments. The diagnostics used for these experiments included an array of b-dot probes, visible framing pictures, visible spectroscopy, and laser interferometry. Characteristics of the switch are determined from spatial and temporal profiles of the magnetic field and the spatial profile and temperature of the switch plasma. Here we present results from experiments for a variety of switch conditions.

Introduction

Plasma flow switches have been used to shorten the current pulse for inductive storage capacitor banks so they can be used to implode plasmas for producing radiation.[1] They consist of two components, an aluminum wire array and a plastic barrier film separated by a few mm. The capacitor bank is discharged initially through the wire array, turning the aluminum wires into a plasma. This is done in a coaxial geometry and thus the JxB forces push the aluminum plasma down the coax. The plasma is collected by the plastic barrier film, which is also heated up to plasma conditions at a time of ~ 1 μs into the current pulse. The combined plasma flows down the coax, conducting current for a time of ~ 3 μs and then passing by a load slot, transferring that current to an implosion load. These switches were originally developed by Turchi[2] and were successfully used on the Shiva Star machine at what was then the Air Force Weapons Lab. These results led Los Alamos to pursue this switching technology for use with their low voltage inductive storage machines.

The switches were used on Pegasus I and II and have also been tried on the explosive generator, Procyon.[3] The results of these experiments have been mixed. Though all of the current is usually switched, not enough voltage is sustained to switch the current rapidly. This is unsuitable for driving an implosion load. This lack of success has led us to consider some of the physics issues associated with plasma flow switches. One of the most important of these is the background plasma density in the channel behind the switch. This comes from the basic physics of the flow of magnetic fields through a plasma. From Ohm's Law we can write

$$\mathbf{E} + \mathrm{v} \times \mathbf{B} = \eta\, \mathbf{J} \sim 0 \qquad 1)$$

where E and B are the electric and magnetic fields and v, η, and J are the velocity, resistivity, and current density. For a magnetic field flowing through a plasma, v is the Alven velocity and the above reduces in mks units to

$$\mathrm{E} = \frac{\mu_0^{3/2}\, \mathrm{I}^2}{(2\pi r)^2 (\rho)^{0.5}} \qquad 2)$$

where ρ is the background ion density, r is the radius, and a coaxial geometry is assumed. This relation implies that the electric field supported by the switch depends on the square of the current and the square root of the background density. Thus the lower one can make the density, the higher

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14. ABSTRACT
We have performed a series of experiments on the Colt facility at Los A.lames to study the performance of plasma flow switches and to understand the important physics issues which affect that performance. These experiments were done in planar geometry on a small machine to allow for better diagnostic access and a higher repetition rate. The Colt facility is a capacitor bank which stores 300 kJ at maximum charge and produced a peak current of 1.1 MA in 2.0 microseconds for these experiments. The diagnostics used for these experiments included an array of bdot probes, visible framing pictures, visible spectroscopy, and laser interferometry. Characteristics of the switch are determined from spatial and temporal profdes of the magnetic field and the spatial profde and temperature of the switch plasma. Here we present results from experiments for a variety of switch conditions.

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the voltage the switch can support. Several factors may affect this density, including plasma boundary layers which form along the walls and the formation or assembly process of the switch. A study of these processes is now the focus of our work.

Since Pegasus is a large machine with many users, the shot rate available to us is low. We therefore have begun utilizing another facility, Colt, which can provide a much higher shot rate with the same current density as on Pegasus. The limitation is that these experiments must be done in planar geometry. This restricts our ability to look into radial effects, but it does provide better diagnostic access to the plasma.

Planar Experiments on Colt

Colt is a 300 kJ capacitor bank with a system inductance of 80 nH. This provides a maximum current between 1 and 2 MA, which is enough to match the current density levels of Pegasus but not for the full Pegasus geometry. The simplest way to produce the same conditions as Pegasus on Colt is to use planar geometry. Using planar geometry will allow us to produce the same current density, the same magnetic field, and use similar mass density switches as we use on Pegasus, but it will not allow us to investigate radial effects.

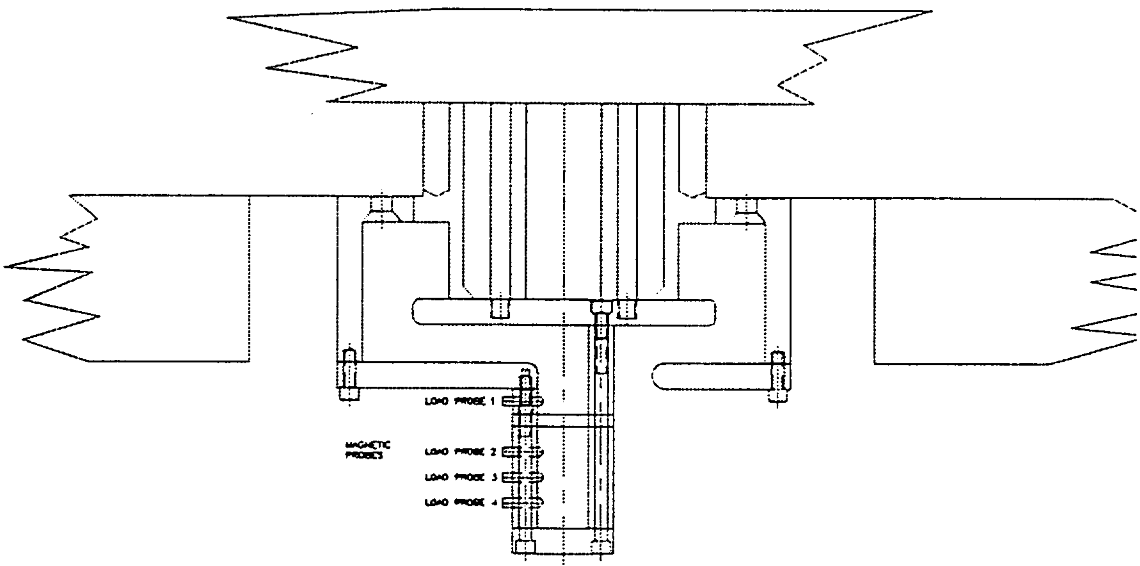

Figure 1. Schematic Diagram of Colt Plasma Flow Switch Experiments.

A series of experiments utilizing planar geometry were designed and fielded on the Colt facility. A schematic showing the experimental configuration is shown in figure 1. In this experiment we fielded four magnetic probes, one above the initial position of the switch and three below, three laser interferometers for measuring the electron density, a multi-frame visible framing camera, and a time resolved spectrometer. Two Rogowski coils were also fielded as machine diagnostics. The series consisted of fourteen shots in which the mass of the aluminum wire array, the thickness of the plastic barrier film, and the distance between the two were varied. It also included a couple of short shots where the machine was fired with a dead short in place of a switch.

The three interferometers were used to measure the plasma density behind the initial position of the switch and the density ahead of the main body of the switch. The density in the switch is too high for the interferometer to measure due to absorption and scattering of the laser light. The framing camera was used to image the plasma from the side, thereby obtaining a measure of the thickness of the current carrying channel as a function of time. The spectrometer consisted of a fiber optic to collect light at the bottom of the power flow channel and fed into a spectrometer which used an OMA as a detector. This gave an integrated measure of the spectrum produced by the plasma.

Experimental Results

The bdot measurements were the diagnostic most able to discriminate among the various

switch designs. An example of these measurements is shown in figure 2.

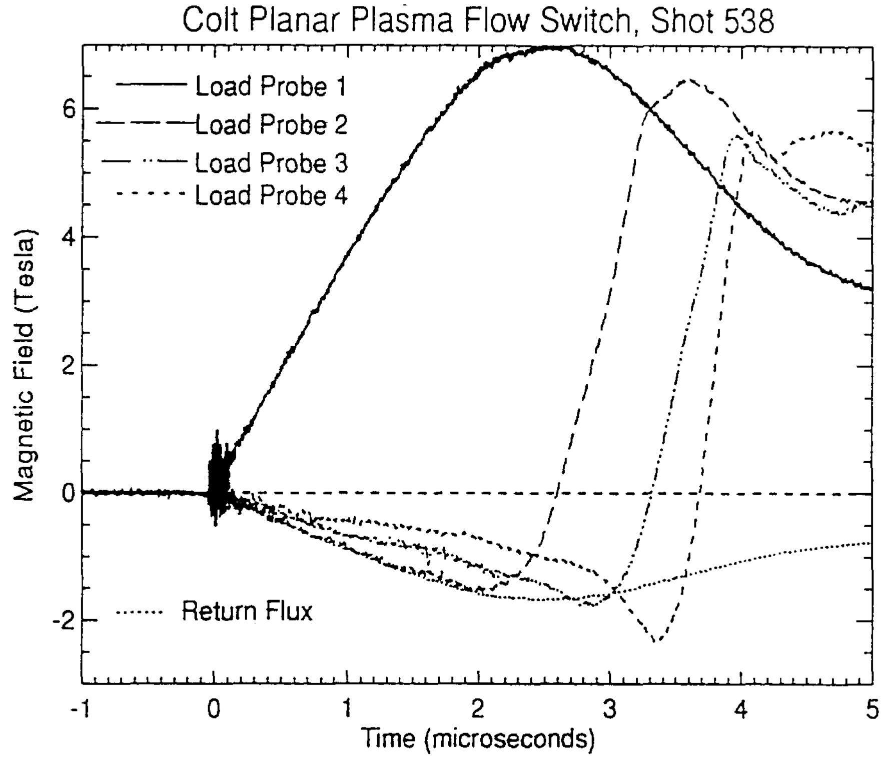

Figure 2. Magnetic field measurements for planar plasma flow switch on Colt.

The field measured by the probe is plotted as a function of time after the start of the current. The negative going field that occurs for load probes 2-4 comes from the return field below the switch plasma since the planar electrodes are not of infinite width. The dotted line which goes through the probes is the scaled return field from the drive. We used these probe traces to determine the best switch performance. The rate of rise of the current in the switch is one key parameter which has an effect on switch performance. It is generally recognized that the faster rate of rise gives better performance. One of the parameter studies which we did was to vary the mass of the switch. By using the rate of rise as measured by the first downstream probe, we determined that a lower mass in the switch gave a faster rate of rise. These results are shown in figure 3. The only exception to the rule of lower mass is better was one shot where the geometry was quite different than previous experiments. In that shot, the separation between wire and plastic was 0 mm.

Another parameter study was done for the separation between wire and plastic. In general, we found that we had better rates of rise for a separation 8 mm. The standard separation we had been using was 6 mm, which we had also tried along with 4 mm separation. The improved rate of rise at 8mm was especially true for the lighter mass switches.

For the rest of the diagnostics, many of the results were generic. The interferometry measurements above the initial position of the switch indicate there is not much plasma away from the walls. Since measurements on Pegasus show plasma density above the switch through the walls, this supports the conclusion that the plasma measured on Pegasus does not come from the switch, but is produced by heating of the walls. The interferometers ahead of the switch measure low density plasma before much current is measured at these locations. As the density rises above a few 10^{16}, the current starts to rise and as the main part of the current arrives, the interferometer quits functioning. This result occurs on every shot and is influenced little by the specifics of the switch.

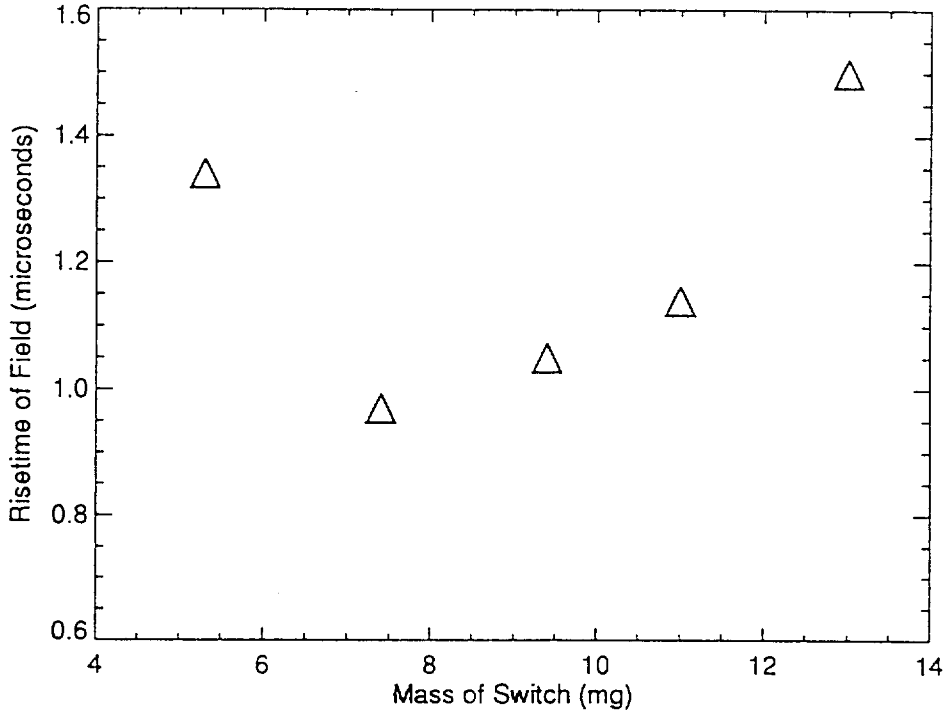

Figure 3. Risetime of the magnetic field as a function of the mass of the switch.

The spectroscopy also is quite generic from shot to shot. The emission was measured at a time of one μs after the start of the current. An example of this measurement is shown in figure 4.

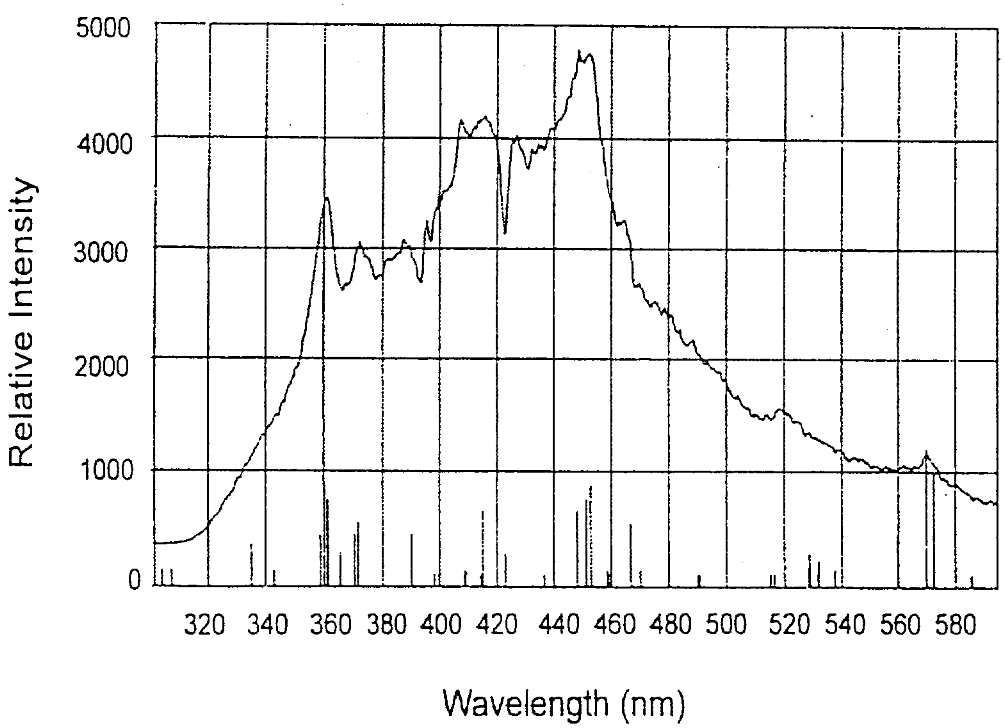

Figure 4. Visible spectroscopy from switch plasma. The vertical lines along the horizontal axis correspond to lines from singly and doubly ionized aluminum.

In this figure, the raw data is shown along with positions of lines from AlII and AlIII. These lines dominate the features of the emission. Also, there are no features which correspond to lines from AlIV or AlI. There are features which correspond to Carbon II lines. For ion densities of 10^{19}, which correspond to the mass densities of the flow switch, these results are consistent with an electron temperature between 2 and 3 eV. This is based on a Saha calculation for ionization balance.

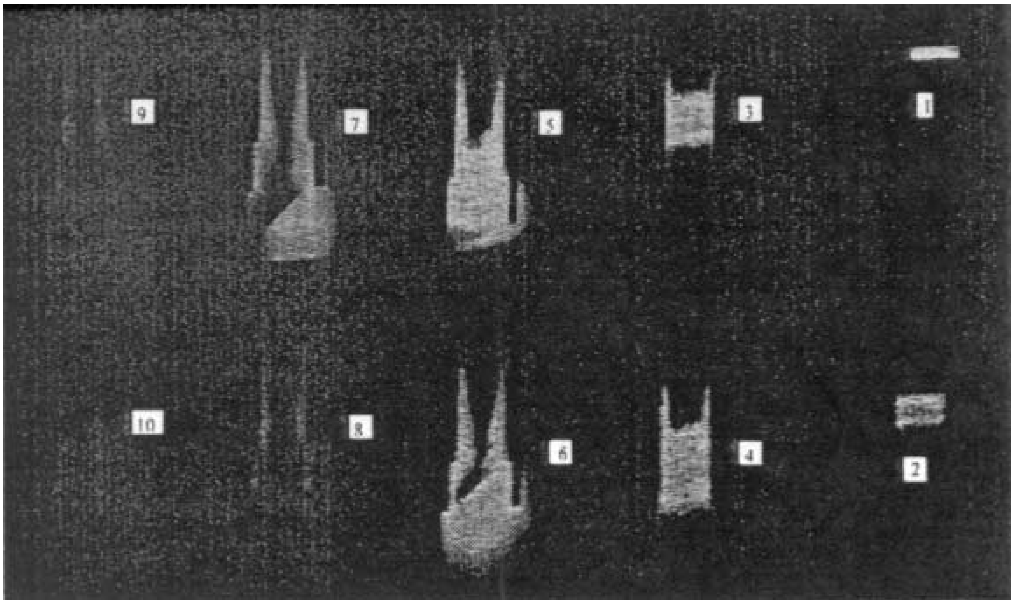

Figure 5. Side on visible framing camera images. Frames are numbered in time ordered manner with first frame taken 0.6 μs after current start and each frame is 1.0 μs later.

The visible imaging also showed a large number of similarities for various switch parameters. An example of this imaging is shown above in figure 5. These images show the plasma flow switch from the side as it is moving down the power flow channel. The scale for the images is that the distance across the switch from left to right is one inch. We can see from these images that the plasma flow switch reaches a thickness of ~ 2.5 cm by the time of peak current at the third frame. In the second frame, which is just after the plastic has turned into a plasma, the switch has two bright regions separated by a darker band. This we believe is due to the explosion of the plastic and the low acceleration of the switch at the early time that this occurs. We note that behind the switch there is a layer of plasma which is laying against the electrodes. This is consistent with simulations of plasma flow switches in the past and can be one source responsible for the large background densities seen in Pegasus experiments. We also note that these plasma layers appear to get thicker as a function of time. One problem we have in these experiments is that the rise time of the Colt machine is too short to increase the acceleration of the switch all the way down the channel. Since the current is therefore dropping at these later times, we do believe the results at these times may not represent the situation on the larger machines.

The bdot results led us to try a series of experiments on Pegasus. These experiments used the lower mass switches as scaled from the Colt experiments and three different separations, 4, 6, and 8 mm. A comparison of the results from these experiments to earlier Pegasus results is shown in figure 6. Here we plot the voltage developed at the entrance to the load slot vs the peak current before switching. The lighter switches performed better than previous experiments, but the best performance was for the switch with 4 mm separation, not the 8 mm. We believe this is due to the effect of a significant radial effect in the acceleration of the aluminum and thus the initial plasma formation of the switch. This effect can not be analyzed in a single Colt experiment, but requires a

careful series studying the formation corresponding to different radii.

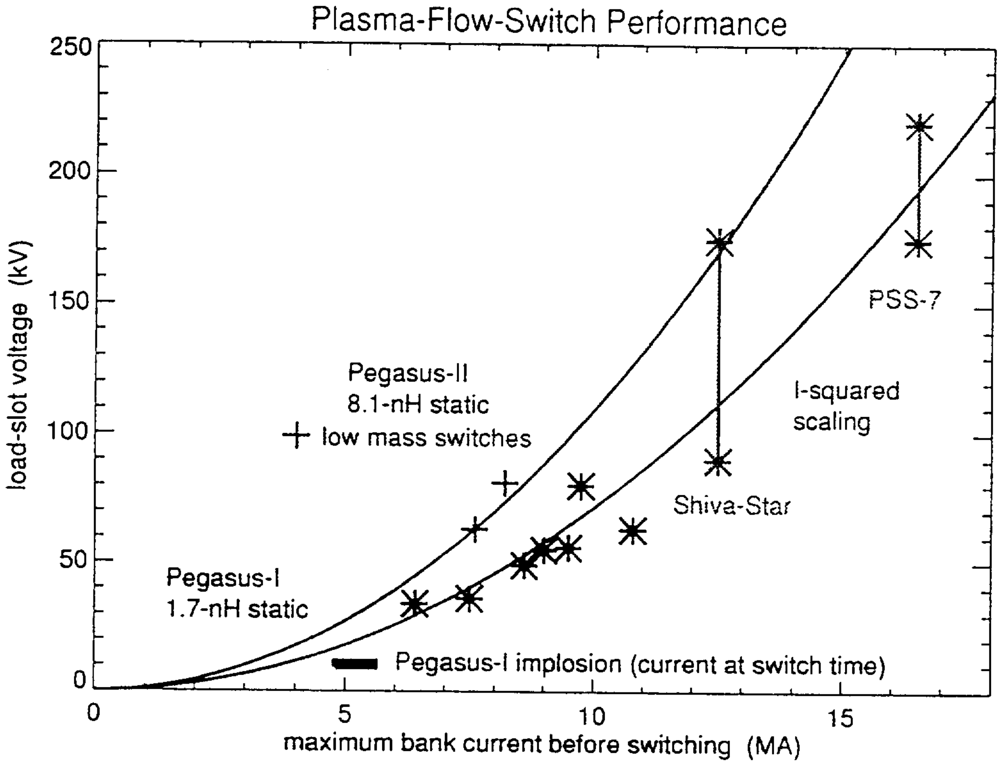

Figure 6. Switch voltage as a function of peak current for plasma flow switches.

Conclusion

We have completed a series of planar plasma flow switch experiments on the Colt facility. These experiments indicated that a higher acceleration of the switch plasma produced better performance. These results were verified on a series of Pegasus experiments. The planar experiments also indicated that a larger separation gave a better formation of the switch. This was not reproduced on Pegasus, and we believe this is due to the large variation in acceleration of the wire array as a function of radius.

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1. J.H.Degnan, et.al., IEEE Trans. Plasma Sci., **PS-15**, 760(1987).
2. P.J.Turchi, "Plasmadynamic Opening Switch Techniques." in Opening Switches, A.H.Guenther, M.Kristiansen, and T.Martin, eds. Plenum Press, N.Y. (1987), p.191-204.
3. J.F.Benage, Jr., et.al. Proceedings of Tenth IEEE Intl. Pulsed Power Conference, ed. by W.L.Baker & G.Cooperstein, p.208.